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Expert systems are being considered for a variety of applications for today's waste manager. Systems are being developed for hazardous waste applications and are now being considered for municipal solid waste disposal activities.

This paper discusses what expert systems are, the benefits of expert systems, development techniques, example hazardous waste systems and considerations that should be evaluated for future systems within the municipal solid waste sector.

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EXPERT SYSTEM TECHNOLOGY
Tools for Developing Intelligent Advisory Systems for Today's Waste Management Programs

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INTRODUCTION

Planning for municipal solid waste treatment and disposal facilities which will meet the present and future needs of our communities requires careful consideration of a number of complex legal, environmental, and economic issues. Often, mere identification of all the issues at hand demands significant research and foresight. The technical issues alone span subjects as diverse as chemistry, geology, hydrology, soil mechanics, and quality assurance to name but a few. Furthermore, community planners have a responsibility to the public and to local industries to acquire considerable skill and experience in all of these areas before making decisions with such broad consequences.

Municipal solid waste is not a new area of concern. State and local governments in conjunction with the private sector have been constructing and operating treatment and disposal facilities for decades. In addition, federal programs and the academic community have sponsored extensive research in this area. Hence there is a formidable body of knowledge and experience concerning the appropriate methods for handling municipal solid waste. However for some communities, especially smaller ones, access to this wide array of expertise may be limited. Consultants and staff engineers having experience with the latest waste processing techniques are in short supply compared to the need. Thus, there is a need to provide engineers and decision makers with information which will yield the most productive and economical municipal waste processing systems. New tools known as expert systems may soon comprise the backbone of advanced technology transfer systems which will allow all communities to share in scientific advances pertaining to waste treatment and disposal.

DESCRIPTION OF EXPERT SYSTEMS

Expert systems are computer programs (software) designed to provide advice in a narrowly defined domain. The expert system is an automated process which incorporates the judgement, experience, rules of thumb, and intuition used by a human specialist to emulate that specialist's problem solving abilities. The objective of these systems is to furnish consistent recommendations concerning particular decision scenarios as would a knowledgeable practitioner in the field.

Expert systems are one product of artificial intelligence research programs which have been ongoing for thirty years in university and computer industry labs. Shortly after the invention of the modern digital computer, it was realized that such a machine was capable not only of mathematical calculations but also of executing a series of logical calculations which simulates a subset of the human thought process. Although sound in theory, development of such systems proved to be an overwhelming task. Early advisory programs, completed in the mid

to late 1970's, required scores of skilled software professionals to develop and expensive dedicated computer hardware to run. These restrictions placed expert systems technology out of the reach of most commercial enterprises.

Two recent advances in the computer field have paved the way for the expert system's transition from research to application. First, knowledge processing software which enables complex symbolic models to be coded quickly and with minimal artificial intelligence programming experience has become widely available. Second, breakthroughs in microelectronics design have increased the computing power to price ratio of digital machinery beyond even the most optimistic predictions of a decade ago. Consequently, serious expert system applications can now be developed and fielded quite economically. Additionally, many of these systems can run on computer hardware that is currently in place for more common engineering and data processing tasks. Finally, the proliferation of personal computer systems has provided more workers than ever before with access to computational resources.

BENEFITS OF EXPERT SYSTEMS

The benefits of applying expert systems technology depend on the problem domain to be addressed. In most cases, expert systems are implemented in hope of decreasing operational costs. An expert's time can be a costly commodity. Obviously, if an automated process can successfully distribute expertise to many problem instances, this system can yield considerable savings.

Note that the expert system is not an attempt to replace domain specialists. Currently, knowledge representation technology is far from the stage where the human thought process can be cloned. Rather, a good expert system can imitate a human expert's responses in a limited problem scope so as to reach similar conclusions in routine or monotonous cases. This liberates the expert so that time can be spent on more complex or research oriented problems.

Conservation of expert resources is not the sole benefit of expert systems. By using an automated system, every solution alternative can be systematically considered. Expert systems do not reach conclusions without first considering all important factors and outcomes. In addition, these factors can usually be examined by a machine much faster than they could manually. An expert system may solve a problem in minutes that could require hours or even days of a human expert's time. Expert systems are also potentially more available than human experts. Domain specialists are generally in high demand. In some cases there may be a significant time interval before an expert becomes available to begin work on a problem.

Another advantage of the automated system is that machines are not subject to time, pressure, or personal constraints. A computer will always deliver consistent responses given consistent input information. In an environment where there are many decision makers and a need for uniformity among them, an expert system can simultaneously increase the quality, consistency, and response time of decisions. Furthermore, an expert system can often be geared to act as a training tool for inexperienced employees. Lastly, creation of a prototype knowledge base can be used as a storage media and organizational mechanism for information in a very dynamic field of study. A knowledge base can depict more complex informational relationships than a database while maintaining greater accessibility to the information than standard technical documentation.

EXPERT SYSTEM DEVELOPMENT TECHNIQUES

To the uninitiated, the prospect of employing an expert system solution is often met with at least some trepidation. Some feel that a computer system, regardless of its sophistication, can never rival human decision making capacities. Others suspect that software errors could corrupt the decision process. Still others fear centralization of the decision making process with an increase in computer intervention. For the most part, these concerns are unfounded and result from a lack of understanding of expert systems and the procedures for their construction. Although implementation details can become quite involved, the general principles of intelligent system development, also referred to as knowledge engineering, can be grasped without a prerequisite understanding of computer operations.

The most common method of knowledge representation in today's expert systems is IF-THEN type rules. The system designer usually performs a literature search and subsequently conducts interviews with one or more domain specialists in order to compile a collection of "rules of thumb" used by the specialists to reach conclusions. Since these rules are not always apparent even to the experts, the designer often asks the experts to solve test problems in order to elicit the logic of the decision making process. Non-standard data types can be used to represent real world objects. These objects and their properties become the subjects of the IF-THEN rules. The first product of this stage of development is known as a rapid or initial prototype. This is typically a small, naive system based upon common knowledge about the problem domain. Sometimes the initial prototype is constructed prior to any interviews so that the experts can see the intended structure of the system at the first meeting.

The next stage of the expert system design process is known as iterative development. This is one of several techniques which distinguishes knowledge based system design from conventional software design. The experts will undoubtedly find many flaws in

the rapid prototype. The criticisms of the experts are impetus for further system development. After each interview, the knowledge engineers implement the additions and modifications suggested by the experts and return for another demonstration. This approach insures that the developers do not misinterpret information gained through the interviews. After several such iterations, the system should evolve to the point where the problem is solved to the satisfaction of both the domain experts and the system developers. Another benefit of iterative development is that it carries with it the first stage of the software quality assurance process. The demonstration sessions should reveal hidden errors in the knowledge base and the user interface software. Comprehensive third party testing, conducted just before deployment of the system, will uncover any additional flaws in the code which might demean the user's decision making proficiency.

Every organization involved in expert systems development work has its own guidelines concerning how the systems will be applied. Systems being developed by EPA are in no way intended to replace decision makers. It is recognized that some situations demand a unique consideration which cannot be provided by an automated process. Furthermore, these systems should not relieve their users or local institutions of the responsibility of decision making. EPA views expert systems as intelligent and efficient screening tools. As such, these programs will complement, not rival current Agency decision making procedures by increasing the productivity and consistency of workers.

EXAMPLE EXPERT SYSTEMS

A few examples of hazardous waste related expert systems are presented in order to illustrate the variety of municipal solid waste decision scenarios that would be amenable to expert system development. CORA is a system developed by CH2M Hill for the EPA Office of Emergency and Remedial Response to aid in the preparation of budget estimates for remediation of Superfund sites. It assists in the screening of cleanup technologies for a site and estimates costs associated with selected technologies. EPA's FY'90 budget estimate for Superfund site remediation was developed with the assistance of this tool. Remediation contractors are also being encouraged to use the system as an aid for estimating costs of remediation of particular sites. Ongoing system refinements will further improve out-year budget estimates. CORKES, which was developed by Roy F. Weston Consulting Engineers, was designed to aid industry comply with SARA Title III Community Right-to-Know reporting requirements. The DEMOTOX system, which was developed by Phil Ludvigsen of Environmental Resources Management, Inc., aids in the evaluation of the groundwater contamination potential of chemical compounds at a site by calculating the mobility degradation indices. This system uses its intelligence features to provide user friendly access to a complex analytical modelling algorithm. The FLEX

system, which was developed by Arthur D. Little Corp. and Computer Sciences Corp. for the EPA Risk Reduction Engineering Laboratory, assists in the evaluation of the chemical resistance of flexible membrane liners based on the results of EPA's Method 9090 test. ESES, which is being developed by Lockheed Corp. for the EPA environmental Monitoring and Support Laboratory in Las Vegas will aid in the design of soil sampling plans for metal and cyanide contaminated soils. Construction Claims, which is being developed by CDM Federal Programs for the EPA Risk Reduction Engineering Laboratory in Cincinnati, will aid in the evaluation of contractor requests for changes to contracts for cleaning up Superfund sites due to unexpected conditions at the sites. It will also aid in assessing potential EPA liabilities associated with the change request. This list of systems should not be regarded as complete but as exemplary of the decision areas within the hazardous waste realm that are being addressed by expert systems. Additional systems are under development to embrace other technical and administrative issues involved in the management and regulation of hazardous wastes.

The knowledge sources and the design features of the cited expert systems differ considerably. For some decision areas, much of the information necessary to make a knowledgeable/informed decision is available in published materials. In these situations the role of expert systems is to facilitate access to this information and to aid in effective use of this information. This will involve evaluation and prioritization of alternative solutions or decision scenarios. The technology screening and cost estimation systems are examples of decisions areas with extensive available literature resources. The role of experts for these types of applications is to provide information concerning new, or esoteric alternatives (treatment methods and applications) and to provide guidance concerning the appropriate depth and breadth of advice for the system. For some decision areas it is necessary to have, or acquire, expertise from a wide range of disciplines. For these types of applications, expert systems provide a means of synthesizing and compiling this diverse information in the format and form required for effective decision making. The soil sampling advisor illustrates this type of system since it contains expertise from the fields of statistical sampling, QA/QC statistics, inorganic chemistry methods, instrumentation, EPA guidelines, etc. For some decisions it is necessary to interpret the results of applying an analytic (mathematical, engineering, etc.) model to some data. In these situations expert systems can assist in model application and interpretation of results. This may involve identification of required inputs, modification of data to satisfy model requirements, and evaluation of model output. In these situations the expert system, which serves as the advisory component for the model, may represent only a portion of the computer code for the overall system. DEMOTOX is an example of this type of system. Expert system technology is not limited to technical applications involving scientific, engineering, or mathematical principles. They can also be used to provided

advice concerning other important decision issues. For example, the Construction Claims expert system, which is currently under development, will aid in the evaluation of contractor requests for contract changes due to unexpected conditions at a remediation site. The primary sources of knowledge for this system will be regulatory policies and case law.

Based on this sample of applications from the hazardous waste area it seems clear that expert system technology offers significant opportunities for improving and expediting the planning processes for, and operations of, municipal solid waste systems.

DESIGN CONSIDERATIONS

The examples of expert systems cited in this paper show that these systems are advisory tools which can be employed in a wide variety of situations to facilitate and expedite decisions. They are, however, not a panacea that can improve every decision process. There is no guarantee that an expert system application will be successful. Some of the factors involved in the success of expert systems will now be briefly discussed. Three interrelated criteria are critical to their success. First, the system must accurately represent/emulate the decision processes used by knowledgeable persons in the field. The system must also produce sufficient increases in decision efficiency and quality to warrant the development and maintenance costs. Finally, the systems must be accepted and employed by the targeted user community. The following questions should be asked before initiation of an expert system development effort:

1. Do experts/knowledgeable persons exist who are available and willing to serve as resources in formulating the decision rules?

2. Is there consensus among the experts and/or user community concerning the decision rules required for the application area addressed by the system?

3. Does the system address a definable need of the targeted user community and will knowledgeable persons from the user community participate in each stage of the development process?

4. Can the knowledge be structured so that the computer can interpret it and the user responses be manipulated to solve the problem?

5. Can a definite plan be developed and resources allocated for regular maintenance of the knowledge base and software?

6. Can a definite plan be developed and resources allocated for providing user support and training to the targeted community?

7. Are decisions in the selected area made often enough to justify undertaking software development and maintenance?

If these questions are answered in the affirmative then the potential developer must explore the scope of the problem to be addressed. If the problem is too simple an expert system will not represent a high enough payoff to justify the time and money spent developing the system. If the problem is too complex the development task will quickly become overwhelming. A rough estimation of problem scope can be measured by the time it takes an expert/knowledgeable person to reach a solution. In general, an expert should be able to arrive at a decision in one to eight hours. Additionally, the decision should be based upon implicit or explicit rules and criteria rather than strictly upon common sense. Fairly consistent responses among experts is also desirable since this will minimize time spent by the knowledge engineer resolving conflicts in the development of the knowledge base.

For several years now, EPA's Risk Reduction Engineering Laboratory in Cincinnati, Ohio has been conducting research into the applicability and development procedures of expert systems in the hazardous waste management arena. Founding an expert systems development effort is neither simple nor inexpensive however, the return on a successful expert system can be sizable. Several guidelines are offered for those contemplating expert system solutions:

1. Close ties must be maintained between the developers and the domain experts. Experts will be more cooperative if they see their suggestions being implemented in the design process.

2. Close ties must be maintained between the developers and the prospective end users. Identify your user community. Contact representatives thereof and discuss your plans with them before system development begins. Users will support your efforts and be more committed to using your system if they see their suggestions being implemented in the design process.

3. Limit the scope of your development effort. Encoding the necessary knowledge for a competent system in a small problem domain is a huge effort. If you attempt to address too broad a problem or if you try to develop a system containing common sense, you will most likely never leave the development stage.

4. Don't underestimate the time required to build a competent system. Initial prototypes can be developed quickly. Moving the system from a prototype to the field will take much longer.

CONCLUSION

This paper began by proposing that expert systems may have a place in the management of municipal solid wastes. No systems have been identified by this author which address these issues, however much success has been achieved in the similar field of hazardous waste management. The youth of this promising

technology explains its absence in many fields moreso than any technical limitations.

Expert system is perhaps an inappropriate term for the software systems described herein. It seems that many are skeptical of a computer system denoted as "expert" while others fear this signifies the first step toward relinquishing control of our institutions to machines. It must be recognized that these systems are merely tools to extend the reach and boost the efficiency of the human mind. In the future, all computer software will be expected to incorporate the cognitive features distinctive of expert systems. With appropriate and careful implementation, these tools can prove to be an invaluable resource to corporate and government decision makers alike.